CALIFORNIA DIVISION OF MINES AND GEOLOGY

Supplement #2 to Fault Evaluation Report FER-13

March 23, 1978

1. Name of fault: Ventura fault.

4. References (additional):

Barrows, A.G., and four others, 1974, Surface effects map of the San Fernando earthquake area in San Fernando Earthquake of February 9, 1971, California Division of Mines and Geology Bulletin 196, plate 3.

Bonilla, M.G., and 11 others, 1971, Surface faulting in The San Fernando Earthquake of February 9, 1971: U.S. Geological Survey Professional Paper 733, p. 55-76.

Bonilla, M.G., 1973, Trench exposures across surface fault rupture associated with the San Fernando earthquake in San Fernando, California, Earthquake of February 9, 1971: U.S. Department of Commerce, NOAA, Vol. III, p. 173-182.

Buena Engineers, Inc., 1975, Preliminary soil investigation for Parcel 5, Mission Plaza Development near east Main Street and Ventura Avenue in the City of San Buenaventura of Ventura County, California: Unpublished consulting report, 21 p., plus appendices.

Buena Engineers, 1977, Tract 2989, northeast corner of Victoria Ave. and Foothill Blvd., Ventura, California: Unpublished consulting report, 5 pages.

Cilweck, B.A., 1974, Geologic/seismic investigation, Hospital Laboratory Addition, Ventura County General Hospital Complex, Project no. 9631: Unpublished report for Ventura County Public Works Agency, 13 pages plus figures and logs.

Cilweck, B.A., June 1975, Geologic/Fault investigation, General Hospital Complex Planning Study, Project 9674: Unpublished report, Ventura County Public Works Agency.

Geotechnical Consultants, Inc., 1977, Geotechnical-seismic investigation of the proposed 330 Zone Water Storage Reservoir and Water Conditioning Facilities Site for the City of San Buenaventura, California: Unpublished consulting report, 19 pages plus plates.

Geotechnical Consultants, Inc., 1978, Geotechnical-seismic investigation, redevelopment Parcels nos. 1, 3, 5, and 10 for the Redevelopment Agency, City of San Buenaventura, California: Unpublished consulting report, 17 pages plus plates.

Gorian and Associates, 1977, Fault rupture investigation, Tract 2542, Telegraph and Hill Roads, City of Ventura: Unpublished consulting report, 5 pages.

Hart, E.W., 1978, Review comments on Mission Plaza Redevelopment site report by Geotechnical Consultants (1978): Unpublished CDMG notes dated 3/21/78, 3 pages.

Heath, E.G., and Leighton, F.B., 1973, Subsurface investigation of ground rupturing during the San Fernando earthquake in San Fernando, California, Earthquake of February 9, 1971: U.S. Department of Commerce, NOAA, v. III, p. 165-172.

Smith, T.C., 1978, Review comments on five consulting reports for site near the Ventura fault, written communication of 3/7/78.

Yerkes, R.F., and Sarna-Wojcicki, A.M., 1978, written communication received 3/7/78 re 1977 and 1978 reports by Geotechnical Consultants (see above references).

Yerkes, R.F., and Sarna-Wojcicki, A.M., 1977, Log of trench at "330 zone" Reservoir Site, Ventura: Unpublished U.S.G.S. data.

5. Summary of available data:

Several additional reports, cited above and pertaining to the Ventura fault, have been received since FER-13 (dated 12/2/76) and the 9/21/77 Supplement to FER-13 were written by T. C. Smith. Data and conclusions from the site investigations cited are summarized and analysed below (discussed from east to west).

a. Geotechnical Consultants (1977) Report. This report is based on continuous trenching (490 feet) and 5 drill holes across a 40-foot high, south-facing topographic escarpment, considered by Sarna-Wojcicki, et al. (1976) to be the surface expression of reverse faulting. The trench and drill data are plotted in detail on Geotechnical Consultants plate 2. This plate clearly shows the alluvial beds to be folded into a monocline (with maximum bedding dips of 23° S), which coincides with the east-west escarpment. Superimposed on the flexure are several faults and fractures with maximum displacements of six inches. (It is noted that the term "fracture" is applied by the consultant to all faults and fractures, regardless of offset.) Although most of the fractures are shown to die-out at depth, 4 faults high on the flexure are shown to increase in displacement with depth. Other than fractures with as much as half an inch offset, no faults were reported in the drill holes. All of the faults and fractures shown on the trench log dip steeply north to vertical, with the north side relatively down. Based on radiometric dating of carbonaceous samples, the ages of the deformed beds range from 15,200± 350 ybp at a depth of 8 feet to more than 40,000 years at a depth of 90 feet.

Geotechnical Consultants conclude (p. 14-15) that "deep subsurface exploration...did not reveal the presence of a major fault, shear zones or severe contortion, offset, and/or significant displacement of earth materials." Moreover, they do not attribute the 40-foot high topographic escarpment at the site to faulting at depth. Instead, they state that the feature is a "zone of monoclinal flexure" and apparently attributed it to "differential ground settlements and lurching" associated with seismic shaking. The recency of monoclinal flexing is implied (p. 16) to be pre-Holocene although they recognize deformation of beds dated at 15,200 years. Nonetheless, they recommend (p. 17) that the fractures are hazardous and should be avoided by the reservoir structure.

In contrast to the above, Smith (in the 9/21/77 Supplement to FER-13) and Yerkes and Sarna-Wojcicki (1977; also 1977 and 1978 oral communications) all of whom also logged the 330 Reservoir site trench, clearly show "faults" on their trench logs. Several of these faults are shown to increase in offset with depth. They attribute the surface deformation, both flexing and faulting, to faulting at a shallow depth. Considering the length (6.5 km) and linearity of the topographic escarpment, no cause other than faulting is considered likely to be the causative mechanism of surface deformation. Moreover, the features observed in the trench are said to be remarkably similar to the features observed in the long trench excavated at the County Hospital site 6 km to the west (see Sarna-Wojcicki, et al., 1976). Based on the 15,200 year date, the recency of faulting and flexing is almost certainly Holocene. The increased displacement of beds at depth (whether due to faulting or folding), would need to be caused by repeated deformation (see Geotechnical Consultants, 1977, plate 2).

b. Gorian Associates (1977) report -- this study (figure 1) consists of a 200-foot long, north-south trench excavated about 100 feet south of the base of the topographic escarpment shown by Sarna-Wojcicki, et al. (1976). No evidence of faulting was reported. A sample of wood collected from a depth of 4.3 feet was dated radiometrically as being 450$\pm$ 220 ybp (Smith, 1978).

c. Buena Engineers, Inc. (1977) report -- the site studied lies just north of Foothill Road, a quarter-mile north of the Ventura fault (figure 1). Approximately 200 feet of trenches were excavated to a depth of 5 or 6 feet in a north-south direction. Although the trench logs were schematic and lacked detail, no evidence of faulting was reported. However, trench log C-C' suggests a sharp flexure (south side down) just north of Foothill Road. The feature is not discussed in the report.

d. Ventura County General Hospital site reports (Cilweck, 1974 and 1975) -- These studies were the first to excavate across the topographic escarpment which was mapped in detail by Sarna-Wojcicki, et al. (1976). Two of the three trenches were located on or across the escarpment and both showed monoclinal flexing. Trench 1, located west of Hillmont Ave. and near the toe of the escarpment showed a sharp, small-scale flexure as shown on figure 3 herein. A larger, faulted monocline was also revealed east of Hillmont (Cilweck, figure 4) in a 340-foot trench. The features shown are similar to those logged by Sarna-Wojcicki, et al. (1976, figure 5), reproduced in FER-13 as figure 3. Numerous faults were observed (maximum offset of 15 miles), some of which could be traced upward to the surface soil horizon. The faults, concentrated along the upper part of the escarpment, mostly dipped steeply northward and showed northside down displacement. However, reverse drag adjacent to several faults suggests a strike-slip component of faulting. A few faults were vertical or dipped southward and showed south side down. Cilweck (p. 5) concluded that the trench exposures "clearly indicate offset or displacement of Terrace Deposits along a series of small faults." He estimated the terrace deposits to be less than 100,000 years old and the most recently disturbed soil to be a few thousand years old. He associated the numerous surface faults with a main fault at a depth of 140 to 240 feet. He believed this fault to be an eastward extension of the Pitas Point fault. Cilweck concluded (p. 7) that the differential uplift across the escarpment and the observed structural features were caused by major fault movement at depth. Based on the disturbance of youthful soils, he stated that the fault "must be considered active."

e. Geotechnical Consultants (1978) -- This report is based on detailed investigations of the Mission Plaza Redevelopment site at the west end of the Ventura fault (figure 2). The investigation consisted of a series of short, discontinuous trenches, 6 drill holes (partly logged visually), and 4 boreholes. The steepness of the topography and existing structures (walls, stairs, etc.), landscaping and fill prevented continuous trenching across the east-west topographic escarpment, believed by Sarna-Wojcicki, et al. (1976) to be the surface expression of the Ventura fault. Based on their observations and interpretations, Geotechnical Consultants (p. 15) believe that the escarpment origin is "unrelated to an active Ventura fault as postulated by the California Division of Mines and Geology and the U.S.G.S." They concluded that there was no hazard from surface fault rupture at the investigated site. It was their opinion (p. 16) that "the escarpment represents a semi-dip slope developed by erosional modification...coincident with the formation of the Ventura Avenue anticline." What they do not explain is 1) what erosional mechanism (e.g. wave cut face or stream bank erosion) produced the escarpment and 2) why no evidence exists for such a process at the site.

It is my opinion, as well as those of Smith (1978) and Yerkes and Sarna-Wojcicki (1978), the report of Geotechnical Consultants has flaws and is inconclusive with regard to the absence of a surface fault-rupture hazard. Some of the reasons for these opinions are:

1) Trenching across the site was discontinuous and the lower part of the scarp was not trenched at all. If the observations in the massive boulder conglomerate in trenches T-5 and T-7 are discounted, the data gap is about 50 feet wide.

2) Correlations between test holes and trenches are often tenuous and alternate interpretations are possible. The data shown on Section B-B' are projected as much as 72 feet, and structural interpretations are highly dependent on the way in which data are projected. Even so, Section B-B' clearly shows that gently dipping terrace gravels cap the terrace above the escarpment and sub-horizontal lagoonal deposits (late Pleistocene and Holocene? ages) lie to the south. The latter units increases in southward dip abruptly as the escarpment is approached (i.e. from south to north) indicating structural deformation since deposition of the lagoonal beds (overlies estuarine beds dated at 23,000+ 920 ybp).

3) Section C-C' also hints at monoclinal flexing where gravel unit G is shown to steepen across the escarpment. Sections A-A' and E-E' likewise show a steepened dip near the scarp, clearly indicating structural deformation along or near the topographic feature.

4) The report lacks a discussion of offsite factors relating to possible recent faulting. This includes the 10 km long escarpment to the east and the clear relationship of that feature to monoclinal flexing with superimposed minor faults (Sarna-Wojcicki, et al., 1976; Cilweck, 1975; Smith, 1977; Geotechnical Consultants, 1977).

5) Although no faults were identified, differential uplift and tilting are strongly indicated across the site. Disappointingly, this type of deformation is not discussed. Based on the 23,000 year age and steep dips (32-36° S) in unit F (a lagoonal deposit), uplift between drill hole DH4 and trench T-6 has amounted to 40 feet over a distance of 80 feet (see Geotechnical Consultants, 1978, plate 1). An average rate of uplift is calculated to be 1 foot/600 years for differential uplift within the 80-foot zone. Part of this uplift could have been along one or more faults lying near and parallel to the escarpment.

Dave Gardner and George Quick of Geotechnical Consultants (p.c., 3/10/78 and 3/17/78) are very confident that no surface fault of significance exists at the redevelopment site. However, I am not convinced they could have detected minor faults, such as were observed to the east at the hospital and reservoir sites, under the physical and geologic conditions existant at the redevelopment site.

f. Buena Engineers, Inc. (1975) -- This report covers the portion of the Mission Plaza Redevelopment site south of Main Street (figure 2). It is a non-definitive study based on shallow boreholes. The report provides no correlation sections and concludes that there is no fault hazard.

8. Conclusions

Based on the investigations of Cilweck (1974, 1975), Sarna-Wojcicki (1976), Smith (1977 Supplement to FER-13), and Yerkes and Sarna-Wojcicki (1977) it is concluded that the topographic escarpment that extends almost continuously for 10 km from Mission San Buenaventura to Harmon fan (figure 1 and 2) marks the surface location of the postulated Ventura fault. The fault is believed to be a north-dipping high-angle reverse fault, probably formed by oblique-slip displacement. The escarpment clearly and precisely coincides with a faulted monocline at the Ventura County General Hospital and at the proposed reservoir site. Although the escarpment varies in width from 30 to 100 meters, the feature is well-defined and continuous for 6.5 km east of Prince Barranca (Eugenia Street). West of Prince Barranca, it is somewhat discontinuous for 2 km, being partly obscured by development and a large landslide. It is continuous linear feature for the next 1.3 km from Hemlock Street to the Mission Plaza Redevelopment site. An extensive investigation (Geotechnical Consultants, 1978) did not identify a significant fault at the latter site. However, differential uplift and local steepening of the youthful strata across the escarpment at that site clearly indicates very recent tectonic deformation. Site conditions probably prevent a conclusive determination as to the existence or absence of faulting, but it is believed likely that the local deformation very probably was caused by Holocene faulting at a shallow depth.

The recency of faulting and monoclinal flexing at the east end of the escarpment is established by the morphologic expression across Harmon Fan, which is considered to be a Holocene deposit (Sarna-Wojcicki, 1976). Also, deformed beds, at a depth of eight feet, were dated at 15,200 ± 350 ybp at the nearby reservoir site. Minimum rates of uplift of 1 foot/1000 years for a 80-foot wide zone and more than 2 feet/1000 years for a 200-foot wide zone can be calculated across the escarpment based on the above age data.

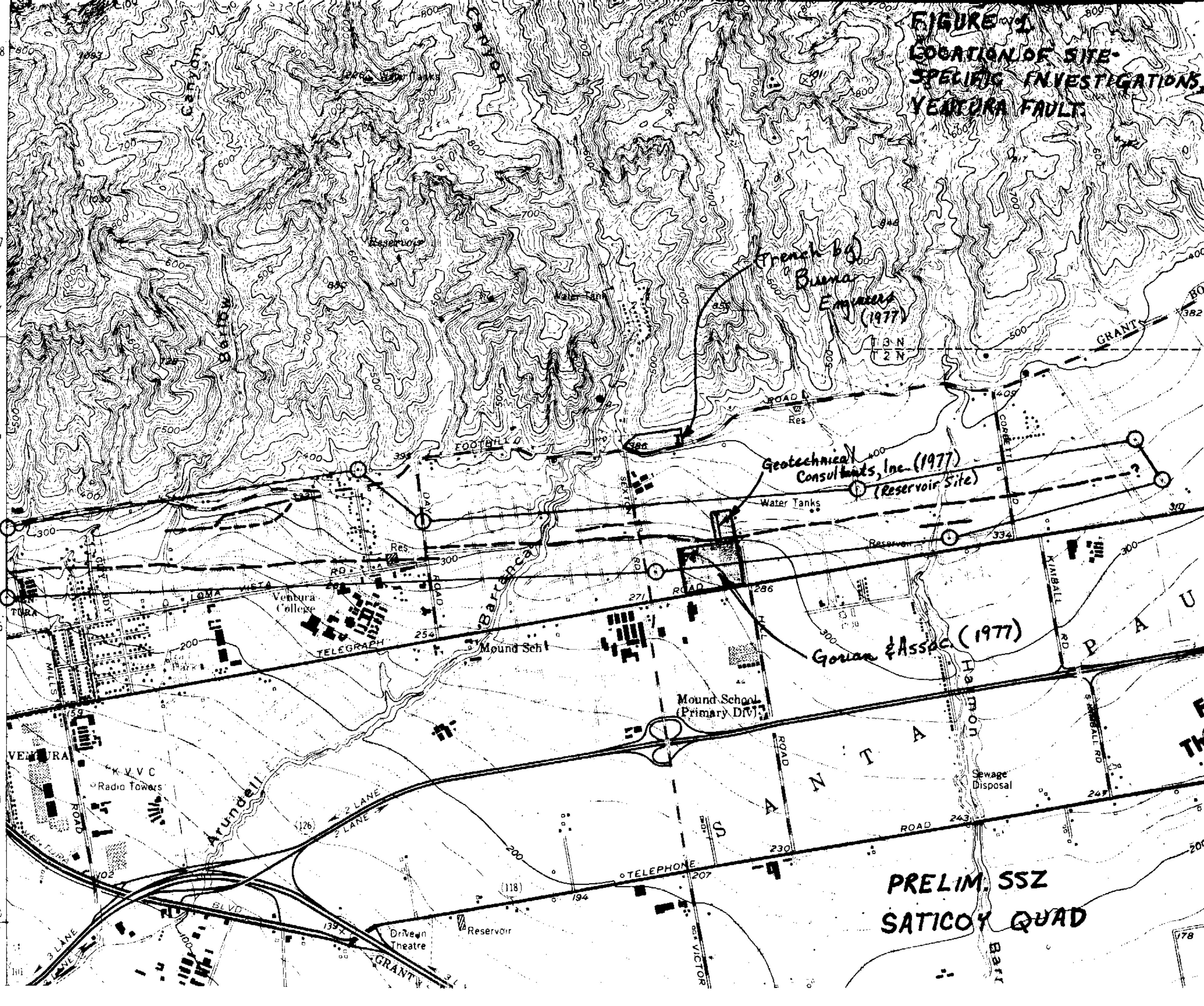
Investigations of two sites todate suggest that recent uplift is expressed at least locally by monoclinal flexing with minor faulting superimposed. However, too few sites have been investigated to be certain this relationship exists everywhere along the length of the escarpment. Observations of the Sylmar and other segments of the San Fernando fault, following the 1971 earthquake, provide some insight regarding the nature of surface deformations. The distribution and magnitude of surface faulting for part of the fault zone are shown on figure 4 (from Bonilla and others, 1973). Barrows, et al. (1975) shows the same information for the entire rupture zone. Note that the width of the Sylmar segment varies in width from less than 100 feet to 600 feet. Although cumulative left-lateral, vertical and compressive deformation were as great as 1.9 m, 1.39 m, and 0.6 m, respectively for this reverse fault (65-70^{o} S dip), maximum displacements on individual (secondary) faults were half this. For the most part, surface faulting was discontinuous and deformation commonly was in the form of surface warping. A good but small-scale example of a fault passing into a monocline is provided in figures 5 and 6. Other examples are provided by Bonilla (1973) and Heath and Leighton (1973). Clearly, faults have difficulty propagating upward through soft alluvial materials and, even when they do, ground rupture may not directly reflect the style, magnitude and precise location of the causative fault. Because of this, I forsee difficulties in evaluating individual sites along the Ventura fault.

9. Recommendations

In my opinion, the Ventura fault meets the criteria of "sufficiently active and well defined" as presently defined by the Division of Mines and Geology (see Special Publication 42, p. 7). I see no substantial basis, the conclusions of Geotechnical Consultants (1978) not withstanding, for reducing or otherwise altering the Special Studies Zones proposed on our Preliminary Review Maps of July 1, 1977 for the Ventura and Saticoy quadrangles.

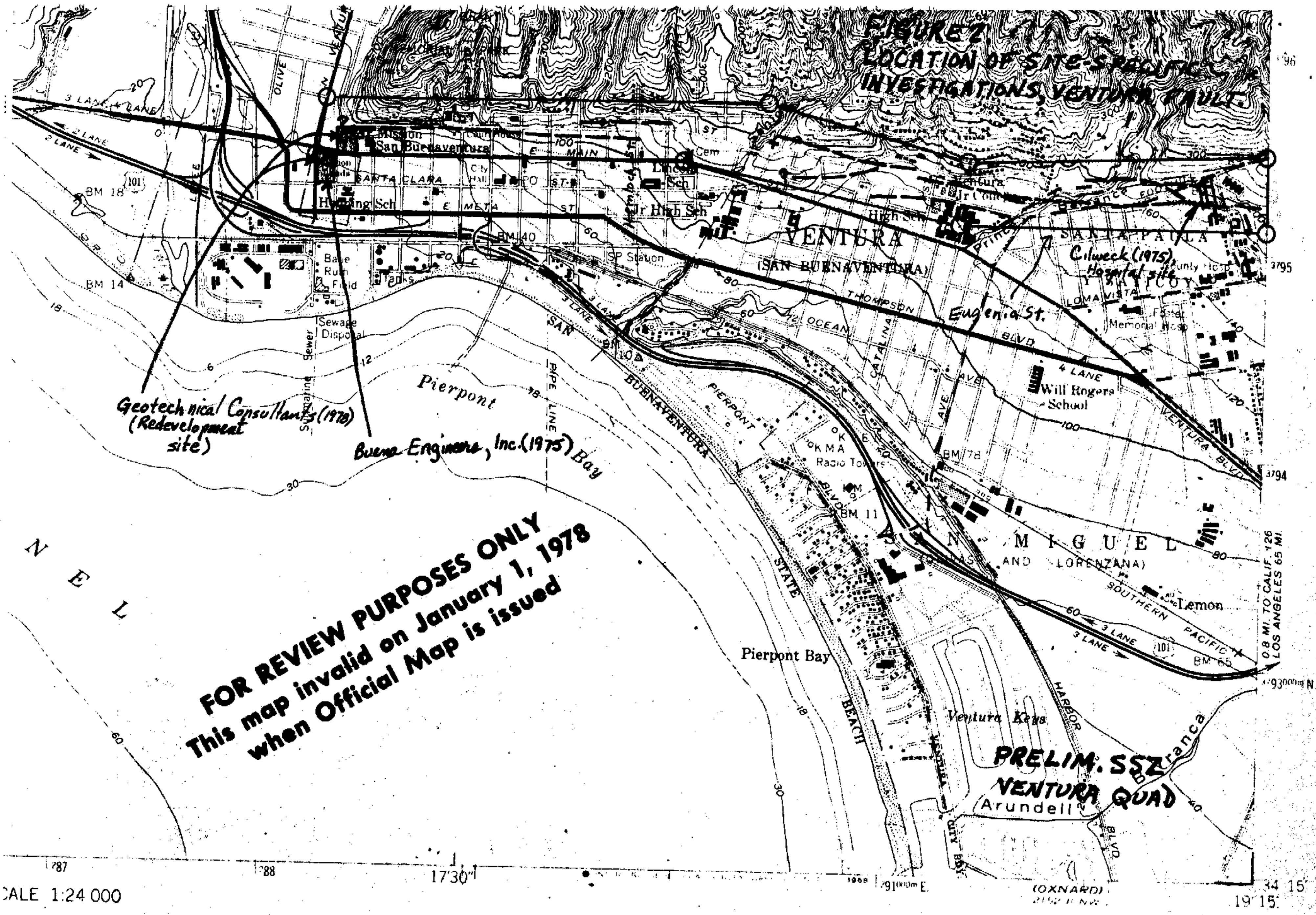
10. Report prepared by: Earl W. Hart, 3/22/78

Earl W. Hart



FER 13 SUPPL 2

FER 13 SUPPL. 2



SCALE 1:24 000

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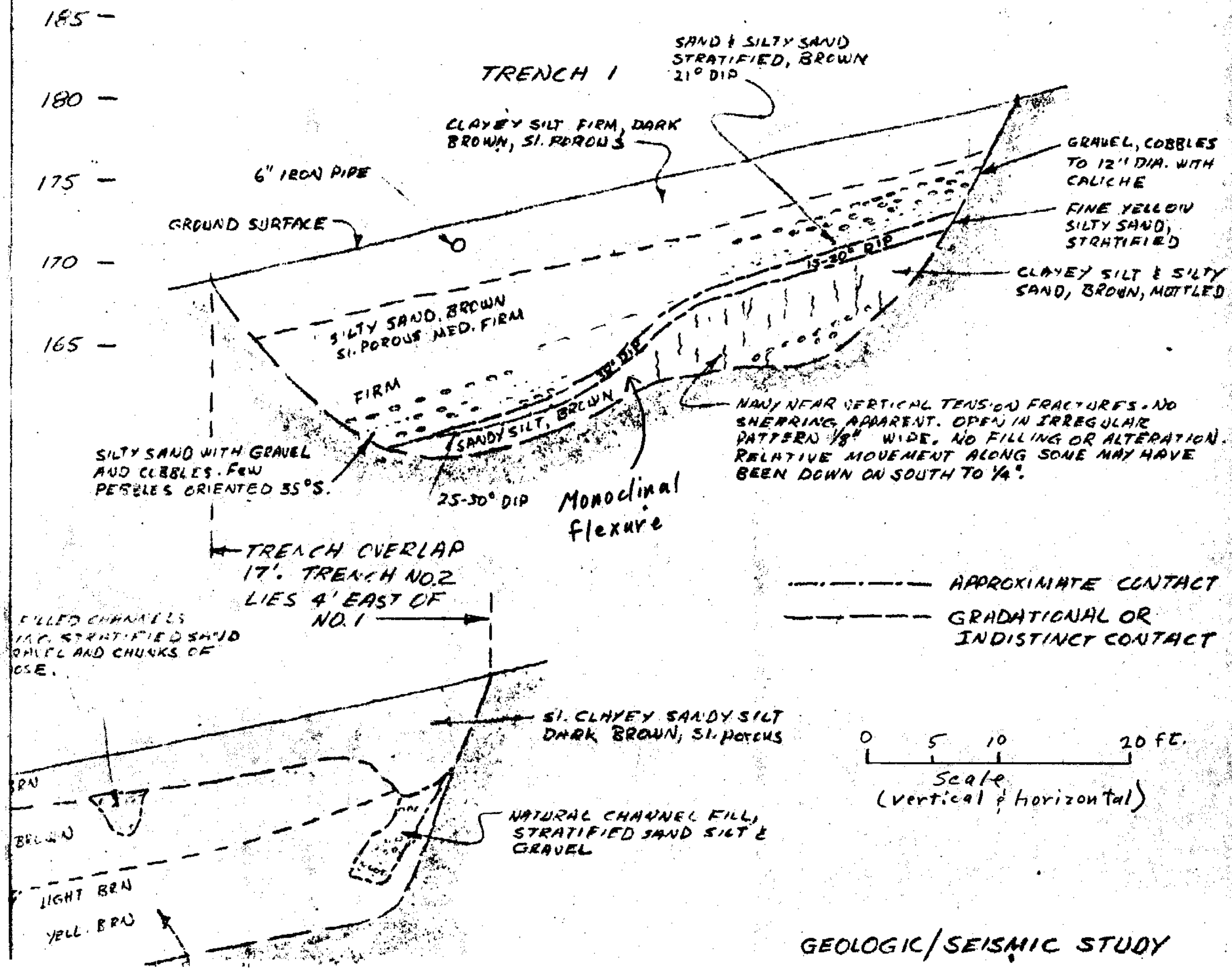
CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT HALF-INTERVAL CONTOURS
DATUM IS MEAN SEA LEVEL

REFERENCES USED TO COMPILE FAULT DATA
Ventura Quadrangle

Sarna-Wojcicki, A. M., Williams, K. M., and Yerkes, R. F., 1976, Geology of the Ventura fault, Ventura County, California: U S Geological Survey Miscellaneous Field Studies Map MF-781

Supplement to FER-13,

Figure 3. Log of Trench 1 (copied from Cilweck, 1975, Fig. 5)



GEOLOGIC/SEISMIC STUDY

FER 13 SUPPL. 2

Figure 4, supplement #2 To FER-13 (from Bonilla, et al, 1971, Fig. 2)

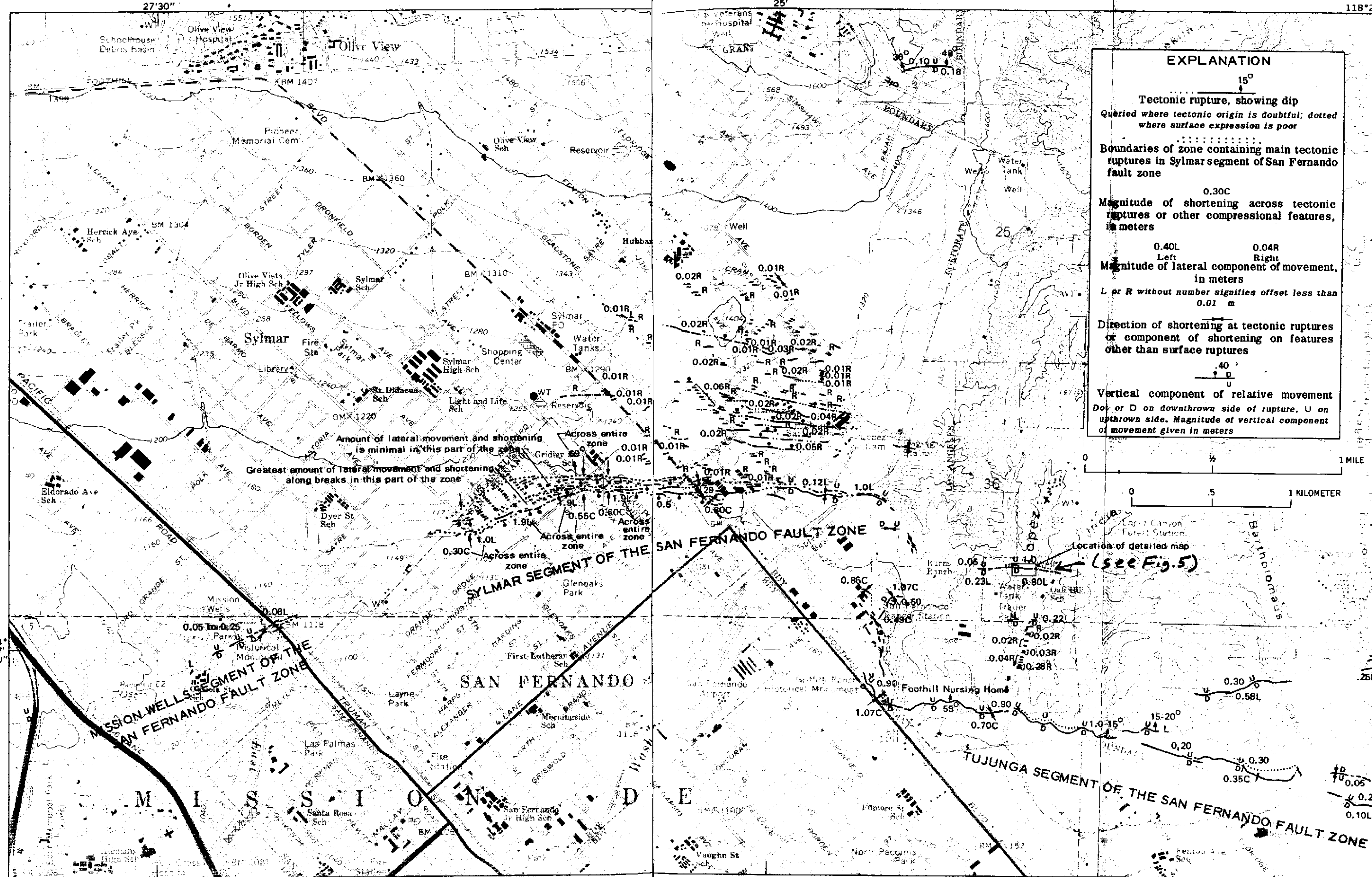


FIGURE 2.—Map showing tectonic ruptures formed during the San Fernando earthquake of February 9, 1971. Figure 2 continues on following pages.

FIGURE 2.—Continued.

Figure 5, supplement #2 to FER-13 (from Bonilla, et al, 197?)

reverse slip and 0.80 m left-lateral slip, or 1.32 m oblique (net) slip.

Near the east end of the scarp, slickensides in the gouge are inclined 58° from the horizontal (fig. 20) which indicates a somewhat lower ratio (0.635) of strike slip to dip slip than was obtained from the displaced bulldozer features (0.76). It is uncertain, however, whether these slickensides formed on February 9 or during an earlier movement on the same fault plane. Both indicate that this was a left-reverse oblique fault according to the classification of Bonilla and Buchanan (1970, p 7–9).

About 0.6 km north of the mouth of Lopez Canyon, a small scarp bulges up the pavement of the Lopez Canyon Road, with the north side elevated about 0.2 m. A roadcut alongside the break exposes disturbed and somewhat slumped sandstone and siltstone, but no positive evidence or prior move-

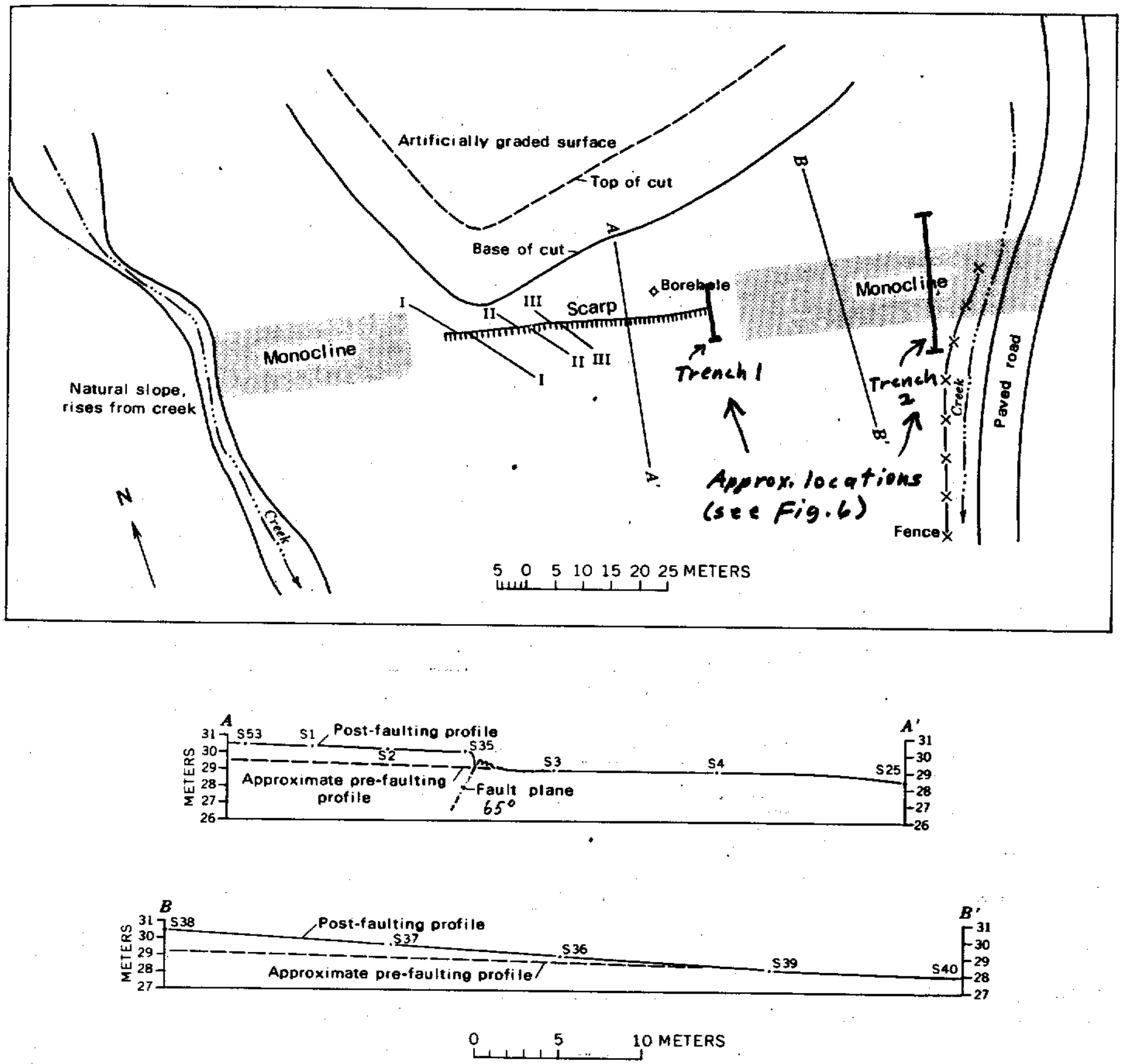


FIGURE 17.—Plan and profiles of trace of fault 0.9 km north of mouth of Lopéz Canyon, based on planetable mapping. For location see figure 2. Elevations on profiles referred to local assumed datum. Numbers preceded by S are field survey stations. See text for details.

Logged by Heath Type of rig 24" backhoe	Northern Trace - Lopez Canyon Pit location	Tract Lopez Canyon Date 3-30-71

ATTITUDES	ENGINEERING GEOLOGY DESCRIPTION		PHYSICAL CONDITION	COMMENTS
① Bedding N77W, 74N	Qal & Sw,	Alluvium and slope wash, silty sand with angular clast of Slt + Ss and well rounded pebbles. Well bedded sand at base, stream deposits with some pebbles and cobbles at base.	Soft-friable	None
② Bedding plane fault N80W, 75N	Slt,	Siltstone, medium gray, iron stain-mass.-highly fractured	Firm	
③ Fault N75W, 62N	Ss + Slt,	Sandstone with thin siltstone interbeds well bedded, beds up to 4' thick.	Firm-hard	NATURAL SLOPE
	Cg + Ss,	Conglomerate and sandstone matrix - white, clean, ig. and meta. clast up to 3"	Firm-hard	None

GRAPHIC REPRESENTATION

Pit trend = North

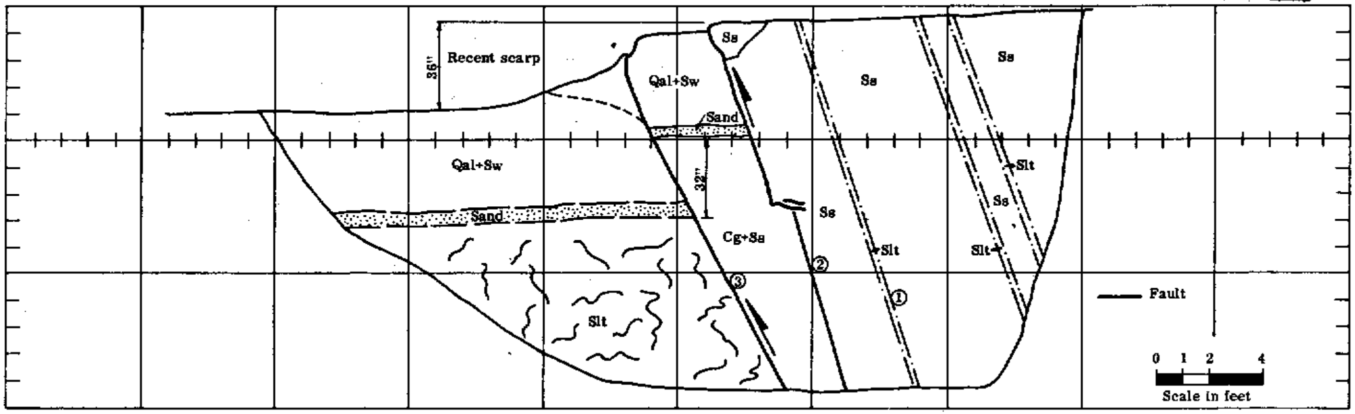


Figure 2.—Geologic pit log for Trench 1.

Logged by Heath Type of rig backhoe	85'E of trench 1, Northern Trace Lopez Canyon Pit location	Tract Lopez Canyon Date 4-12-71

ATTITUDES	ENGINEERING GEOLOGY DESCRIPTION		PHYSICAL CONDITION	COMMENTS
None	Qal,	Alluvium, light gray sand and some gravel, deposited on fill, as late as spring floods of 1969, crudely bedded.	Soft and friable	No faulting in trench 36"-42" uplift on north side by warping only
	Fill,	Dark gray brown, mass to poorly laminated, sandy	Soft	
	Soil,	Dark brown-black, carbonaceous, buried grass and roots.	Soft	
	Qalo,	Light gray, older alluvium, gravel and boulders in sand.	Soft-firm	NATURAL SLOPE
				Graded flat

GRAPHIC REPRESENTATION

Pit trend= N3E

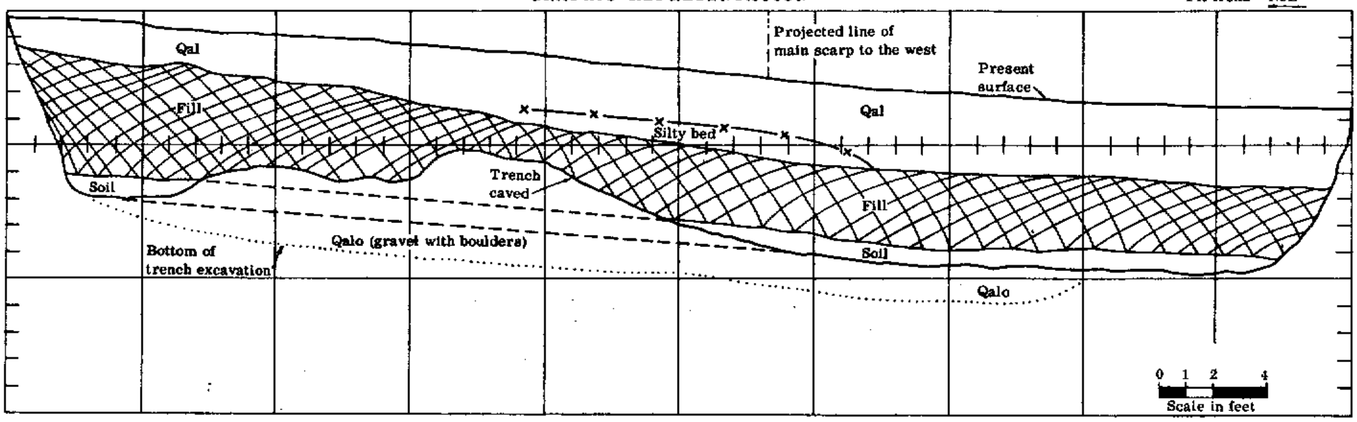


Figure 3.—Geologic pit log for Trench 2.

Figure 6, Supplement #2 to FER-13 (from Heath and Leighton, 1973, p.168)